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Development an Augmented Reality-Based Mathematics Application to Improve Junior High School Students' Comprehension of Mathematical Concepts

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Abstract: Mathematics education at the junior high school level faces challenges in helping students visualize three-dimensional geometric concepts using traditional methods. Augmented reality (AR) has been proposed as a potential solution due to its ability to provide interactive 3D representations, yet research on its implementation in Indonesian schools remains limited. This study aims to develop and evaluate an AR-based mathematics application to improve students' conceptual understanding of geometry. Using the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), the study involved 45 students in field trials, preceded by individual (5 students), small group (12 students), and large group (20 students) trials. Data were collected through teacher questionnaires, student questionnaires, pre-tests, and post-tests, with instrument validation conducted through expert review. Descriptive and inferential statistical analyses were applied to measure learning effectiveness. The results show a significant improvement in students' ability to visualize geometric concepts, with average scores increasing from 46.31 (pre-test) to 92.91 (post-test). The findings suggest that AR technology can enhance engagement and comprehension in mathematics learning. However, implementation challenges, such as access to AR-compatible devices and teacher readiness, require further study. This research contributes to the integration of AR in mathematics education and highlights its potential for broader adoption in schools with adequate technological infrastructure.

Keywords: Augmented reality, mathematical concept comprehension, geometry, junior high school

Abstrak: *Pendidikan matematika di tingkat sekolah menengah pertama menghadapi tantangan dalam membantu siswa memvisualisasikan konsep geometri tiga dimensi menggunakan metode tradisional. Augmented reality (AR) telah diusulkan sebagai solusi potensial karena kemampuannya untuk menyediakan representasi 3D interaktif, namun penelitian tentang penerapannya di sekolah-sekolah Indonesia masih terbatas. Studi ini bertujuan untuk mengembangkan dan mengevaluasi aplikasi matematika berbasis AR untuk meningkatkan pemahaman konseptual siswa tentang geometri. Menggunakan model ADDIE (Analisis, Desain, Pengembangan, Implementasi, Evaluasi), studi ini melibatkan 45 siswa dalam uji lapangan, yang didahului oleh uji individu (5 siswa), uji kelompok kecil (12 siswa), dan uji kelompok besar (20 siswa). Data dikumpulkan melalui kuesioner guru, kuesioner siswa, pre-test, dan post-test, dengan validasi instrumen dilakukan melalui tinjauan ahli. Analisis statistik deskriptif dan inferensial diterapkan untuk mengukur efektivitas pembelajaran. Hasilnya menunjukkan peningkatan signifikan dalam kemampuan siswa untuk memvisualisasikan konsep geometris, dengan skor rata-rata meningkat dari 46,31 (pre-test) menjadi 92,91 (post-test). Temuan tersebut menunjukkan bahwa teknologi AR dapat meningkatkan keterlibatan dan pemahaman dalam pembelajaran matematika. Namun, tantangan implementasi, seperti akses ke perangkat yang kompatibel dengan AR dan kesiapan guru, memerlukan studi lebih lanjut. Penelitian ini berkontribusi pada integrasi AR dalam pendidikan matematika dan menyoroti potensinya untuk adopsi yang lebih luas di sekolah-sekolah dengan infrastruktur teknologi yang memadai.*

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Kata Kunci: *Augmented reality, pemahaman konsep matematis, geometri, sekolah menengah pertama*

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INTRODUCTION

Mathematics education in Indonesia faces persistent challenges, particularly in the teaching of geometry, which requires students to visualize three-dimensional (3D) shapes. Muhtadi & Wulandari (2023) found that many students struggle to mentally represent geometric forms, making it difficult to understand relationships between shapes in real-world contexts. This difficulty stems from traditional instructional methods such as relying on textbooks and blackboards, that fail to provide concrete visual representations. Gusteti et al. (2024) argue that passive learning environments hinder student engagement, further exacerbating difficulties in geometry comprehension.

Despite rapid advancements in educational technology, many Indonesian schools have not yet adopted AR-based learning (Sugiarso et al., 2024). Mallem (2010) highlights that AR has the potential to enhance geometry learning by allowing students to interact with 3D objects, improving spatial reasoning (Hilda & Lubis, 2021). However, studies on AR in Indonesian junior high schools remain scarce, particularly in understanding its practical implementation and impact on learning outcomes (Andriani et al., 2024).

This study addresses the research gap by developing and evaluating an AR-based mathematics application tailored to junior high school students. Compared to prior studies, this research examines not only the effectiveness of AR in visualizing geometric concepts but also its impact on student engagement and collaboration. Furthermore, this study identifies implementation challenges, providing insights into how AR can be integrated into school curricula.

RESEARCH METHODS

This study employs a Research and Development (R&D) approach, utilizing the ADDIE model (Branch, 2009) to guide the development of an Augmented Reality (AR)-based mathematics application for junior high school students. The ADDIE model consists of five stages, each with specific objectives and implementation strategies. In the analysis stage, a needs analysis was conducted to identify challenges students face in visualizing three-dimensional (3D) geometric objects. This was done through student questionnaires (111 students), which assessed the limitations of traditional learning methods and the potential benefits of integrating AR. During the design stage, the development of the AR application focused on seven geometric shapes (cube, cuboid, prism, pyramid, cone, cylinder, and sphere), incorporating interactive elements such as rotation, scaling, and cross-section views to enhance conceptual understanding. The application framework was structured to align with the learning objectives and lesson plans within the mathematics curriculum. The development stage involved constructing the AR application using Unity 3D and Vuforia SDK, ensuring marker-based AR interactions that allow students to manipulate 3D geometric models. Before implementation, the application underwent expert validation by one media experts and one subject matter experts. The validation process focused on content accuracy, pedagogical suitability, and technical usability. Based on expert feedback, necessary revisions were made to enhance the application's instructional effectiveness. The implementation stage consisted of three levels of testing: individual trials (5 students), small group trials (12 students), and large group trials (20 students). These trials assessed learning quality with media, quality of media, understanding, and problem-solving uses of media. A field trial involving 45 students was then conducted, using pre-tests and post-tests to measure conceptual

improvements. Additionally, teacher questionnaires were distributed to validate student responses and assess the learning quality with media, media quality, and effectiveness in learning. The evaluation stage focused on analyzing the effectiveness of the AR application in improving students' understanding of geometric concepts. Data were collected from pre-test and post-test scores, student and teacher questionnaire responses. The statistical analysis included descriptive statistics and inferential statistics (comparative statistics) to determine the impact of the AR intervention on student learning outcomes.

Table 1. Participant Selection Criteria

Participant Group	Selection Criteria	Sample Size
Students (Field Trial)	Grade 8 students with prior exposure to geometry but no AR experience	45
Teachers	Junior high school mathematics teachers with at least 3 years of experience	1
Media Experts	Educational technology specialists	1
Subject Matter Experts	University specializing in mathematics education	1

Table 2. Data Collection Instruments and Validation

Instrument	Purpose	Validation Process
Student Questionnaire	Evaluate engagement and usability of AR learning	Expert validation (face validity)
Teacher Questionnaire	Validate student responses and assess pedagogical feasibility	Expert validation (face validity)
Pre-test & Post-test	Measure conceptual improvement in geometry	Expert validation (content validity)

The collected data were analyzed using both quantitative and qualitative approaches. Descriptive statistics were used to determine the mean of student and teacher questionnaire responses, which were further categorized into low, medium, and high engagement levels. To evaluate the effectiveness of the AR application, a comparative statistics was conducted to compare pre-test and post-test scores. This test assessed whether the observed improvement in students' understanding was statistically significant.

RESULTS AND DISCUSSION

Student Learning Outcomes

The pre-test and post-test analysis shows a significant increase in students' ability to visualize and understand geometric concepts.

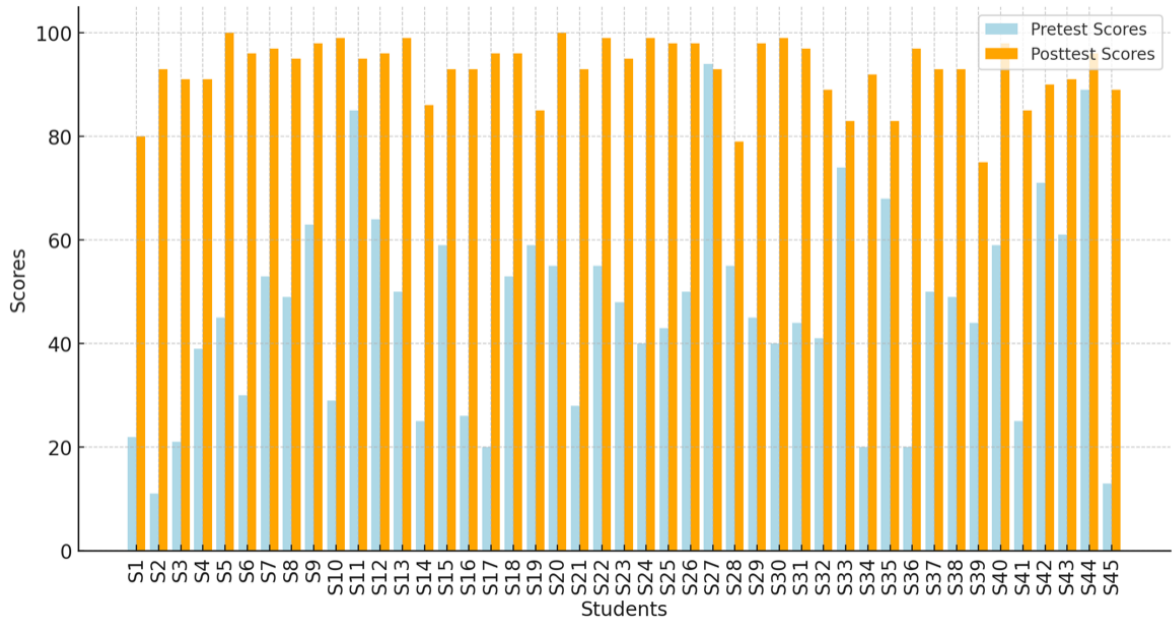

Figure 1. Comparison of Pre-test and Post-test Scores

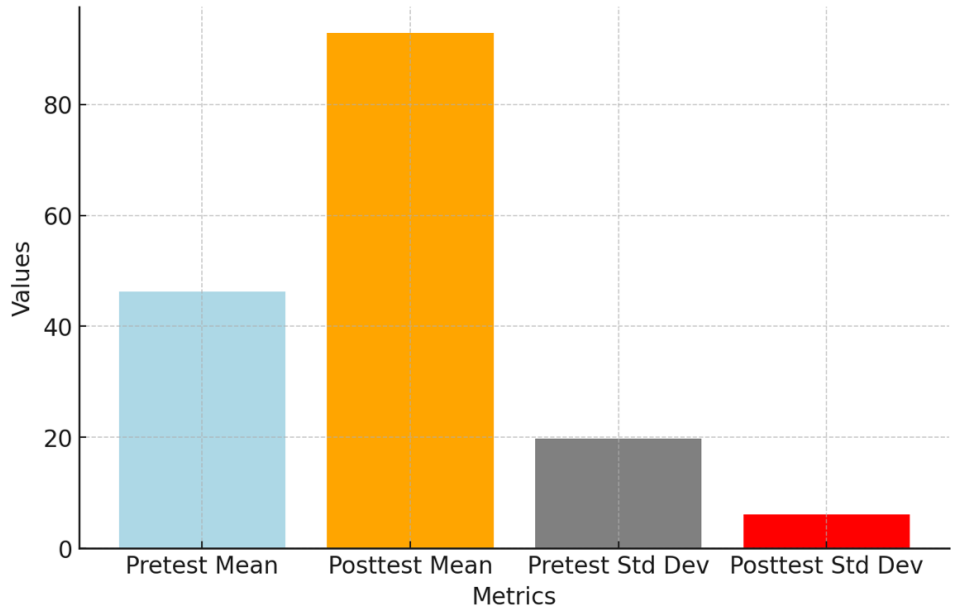

Figure 2. Statistical analysis of pretest and posttest results

The bar charts illustrate the significant impact of the augmented reality (AR) mathematics application on students' understanding of geometry. The first chart, comparing pretest and posttest scores, shows a clear improvement in student performance. Before using the AR application, most students had low to moderate scores, with many struggling to grasp geometric concepts. However, after interacting with the AR-based learning tool, their scores increased significantly, with several students achieving near-perfect marks. This demonstrates that the interactive and visual nature of AR helped students better understand abstract mathematical concepts, making learning more engaging and effective.

The second chart presents a statistical summary of the test results, further reinforcing these findings. The average pretest score of 46.31 suggests that students initially had difficulty

comprehending geometry. However, the average posttest score of 92.91 confirms that the AR application played a crucial role in enhancing their understanding. Additionally, the pretest standard deviation was relatively high (19.75), indicating significant variations in students' prior knowledge. In contrast, the posttest standard deviation dropped to 6.08, showing that after using the AR application, students' comprehension levels became more consistent. This suggests that the AR-based learning approach not only improved overall performance but also reduced gaps in understanding among students.

Overall, these results highlight the effectiveness of augmented reality as a learning tool for mathematics, particularly in topics that require spatial reasoning, such as geometry. The AR application successfully transformed abstract concepts into interactive 3D experiences, helping students visualize and manipulate geometric shapes more effectively. The findings suggest that integrating AR into classroom instruction can enhance student engagement, improve comprehension, and create a more equitable learning experience for all students.

Teacher and Student Responses

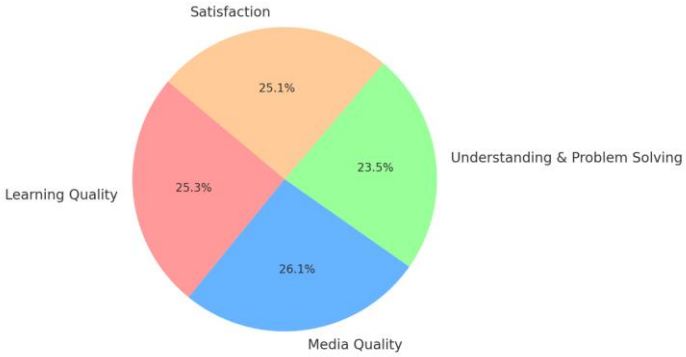

Figure 3. Individual Trials

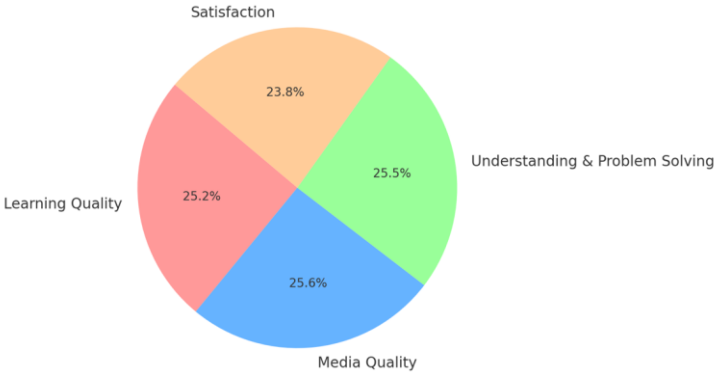

Figure 4. Small Group Trials

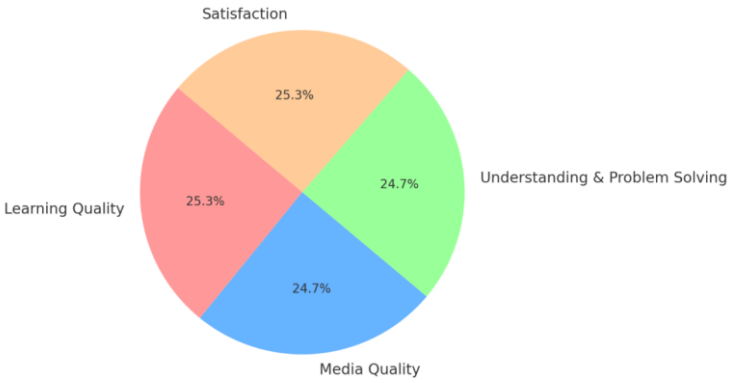

Figure 5. Large Group Trials

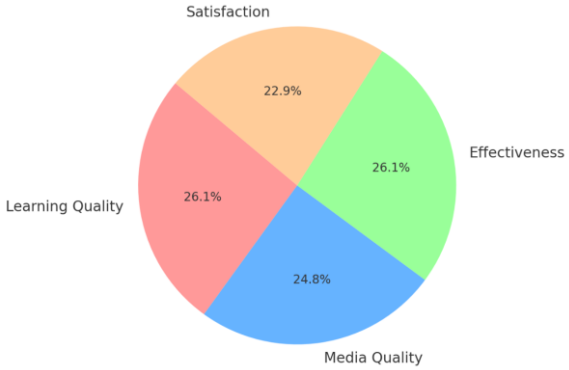

Figure 5. Teacher responses

The pie charts illustrate the effectiveness of the augmented reality (AR) mathematics application across different trial settings and teacher evaluations. In individual trials, students rated learning and media quality highly, indicating that they found the application engaging and visually appealing, though understanding and problem-solving scored slightly lower, suggesting challenges in grasping concepts independently. Small group trials showed overall improvement, particularly in understanding and problem-solving, as collaboration helped students clarify concepts, while media quality remained consistently high. However, large group trials saw noticeable declines in ratings, especially in understanding and problem-solving, likely due to limited teacher assistance or technical difficulties in managing multiple users, with media quality also slightly affected by navigation issues. Teacher evaluations provided a different perspective, consistently rating learning quality and effectiveness highly, as they found the AR application valuable in enhancing students' understanding of geometric concepts. However, media quality received slightly lower ratings, possibly due to minor usability concerns. Despite some challenges in larger classroom settings, both students and teachers expressed overall satisfaction, reinforcing the application's potential for improving mathematics learning while highlighting areas for further enhancement.

Overall, these findings suggest that the AR application is most effective when used in small group settings, where students can collaborate and receive guidance. While individual trials showed positive results, some students required additional support, particularly in problem-solving. In large groups, challenges became more evident, indicating the need for better instructional strategies or technical adjustments. Teachers were highly supportive of the AR application, recognizing its ability to enhance geometry learning. However, refinements in user experience and accessibility may further optimize its impact in classroom environments.

This study demonstrates several strengths in the development and implementation of an AR-based mathematics application. One of the key strengths is its high effectiveness, as evidenced by a significant improvement in students' geometry comprehension. The substantial increase in post-test scores compared to pre-test scores indicates that the AR application effectively enhances students' ability to visualize and understand three-dimensional geometric concepts. Another strength is that the learning tool was validated by experts, ensuring both content accuracy and usability. The involvement of media and subject matter experts in the development phase helped refine the application, making it more pedagogically sound and user-friendly. Additionally, the interactive nature of AR technology fosters student engagement and spatial reasoning, making abstract mathematical concepts more tangible and easier to comprehend.

Despite these strengths, the study also has several limitations. One major challenge is access to AR devices, as not all schools have the necessary technological infrastructure to support AR-based learning. Limited availability of smartphones, tablets, or AR-compatible devices could hinder the widespread adoption of this learning tool. Another limitation is teacher preparedness, as effective integration of AR into the classroom requires additional training for educators. Lastly, the sample size in this study was limited to one school, which may affect the generalizability of the findings. Future research should involve a broader sample to ensure that the effectiveness of the AR application can be validated across diverse educational settings.

To further strengthen the impact of AR-based learning, future research should explore long-term retention effects to determine whether students can maintain their improved comprehension over time. A longitudinal study tracking student performance beyond the initial implementation phase would provide deeper insights into the sustained benefits of AR-enhanced geometry instruction. Additionally, future studies should investigate the scalability of AR applications in schools with limited resources, addressing potential barriers such as device accessibility and teacher training. Understanding how AR can be adapted to different educational environments will help promote wider adoption of the technology. Moreover, research should focus on expanding AR applications to other mathematical topics, exploring how this interactive technology can enhance learning in algebra, trigonometry, and other complex mathematical concepts. By broadening the scope of AR-based education, future studies can contribute to the development of more inclusive and effective digital learning tools.

CONCLUSIONS AND RECOMMENDATIONS

This study confirms that AR-based mathematics applications significantly enhance students' understanding of geometric concepts. The integration of 3D visualization improves spatial reasoning, making abstract concepts more tangible. Despite its effectiveness, challenges remain in technology accessibility and teacher training. Future research should focus on scalable AR solutions and their long-term impact on mathematics education.

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